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SUMMARY

The objective of this study was to evaluate the soil parameters and dendrometric characteristics of a 30-month-old *Eucalyptus grandis* plantation in a hillside area in the municipality of Itajaí, Santa Catarina, Brazil. Four sampling units were randomly allocated at four altitudinal levels: the top (145 m), 30 m (132 m), 20 m (122 m), and base (105 m). The diameter at breast height (DBH) and height of all trees were measured in each sampling unit. Soil samples were collected to determine the following parameters: clay, organic matter, base saturation (V), cation exchange capacity (CEC), pH in water, potential acidity (H+Al), aluminum (Al), phosphorus (P), potassium (K), calcium (Ca), magnesium

(Mg), and sodium (Na). The statistical analysis indicated that the position in the relief only influenced CEC, pH, H+Al, K, and Na. The highest averages of CEC (44.88 $cmol_c$ dm^3) and H+Al (44.97 $cmol_c$ dm^3) were observed at the top. In contrast, the highest values of pH (4.17), K (41.25 mg kg^{-1}), and Na (14.75 mg kg^{-1}) were observed at the base. Regarding the dendrometric parameters, only the density of individuals and the diameter at breast height were influenced by the position in the relief. The highest density was found at the base (2,250 individuals), where individuals with smaller diameters were observed. In contrast, the highest DBH values were observed at 30 m depth (11.36 cm). The soils in this study were acidic and dystrophic. Therefore, small variations in relief form conditioned variability in soil attributes and growth of *E. grandis* at 30 months of age.
Keywords: of soil chemical attributes, density of individuals, growth.

INTRODUCTION

The wide range of *Eucalyptus* species adapted to different soil and climatic conditions, associated with the easy propagation of seeds and cloning, allows the adaptation of stands to various tropical and subtropical regions of Brazil (Gonçalves et al., 2013). The need for wood for various purposes has led to the establishment of eucalyptus plantations for multiple uses (Gonçalves et al., 2013).

However, several factors limit or impose restrictions on reforestation, influencing plant growth and survival (Breugel et al., 2011). This includes steep slopes. The soils in these areas have distinct characteristics due to their relief form. The surfaces that make up the relief influence the exposure of the source material, the direction of water flow in the soil profile, and the intensity and occurrence of erosion and leaching processes (Artur et al., 2014).

Solar radiation is the primary energy source of many physical and biological processes on the planet, and topography is the main factor that modifies its distribution at the landscape level (Chagas et al., 2013). Therefore, variations in soil attributes and, consequently, in plant growth depend on the position of the soil in the landscape and the processes of drainage, erosion, and deposition (Meireles et al., 2012).

The slope and soil form affect the absorption and storage capacity of water, the diversity of animal and plant species, the redistribution of soil particles, and the contents of organic matter and nutrients, resulting in changes in soil attributes in a way that affects the possibilities of land use, and, consequently, the development of plants (Arthur et al., 2014). However, few studies on *Eucalyptus* reforestation have been conducted in slope areas. A literature search did not reveal any studies on this topic in the Vale do Itajaí region in Santa Catarina (SC), Brazil. Given the above, the present study aimed to evaluate the soil parameters and their relationship with the dendrometric characteristics of a 30-month-old *E. grandis* plantation in a hillside area in the municipality of Itajaí, SC, Brazil.

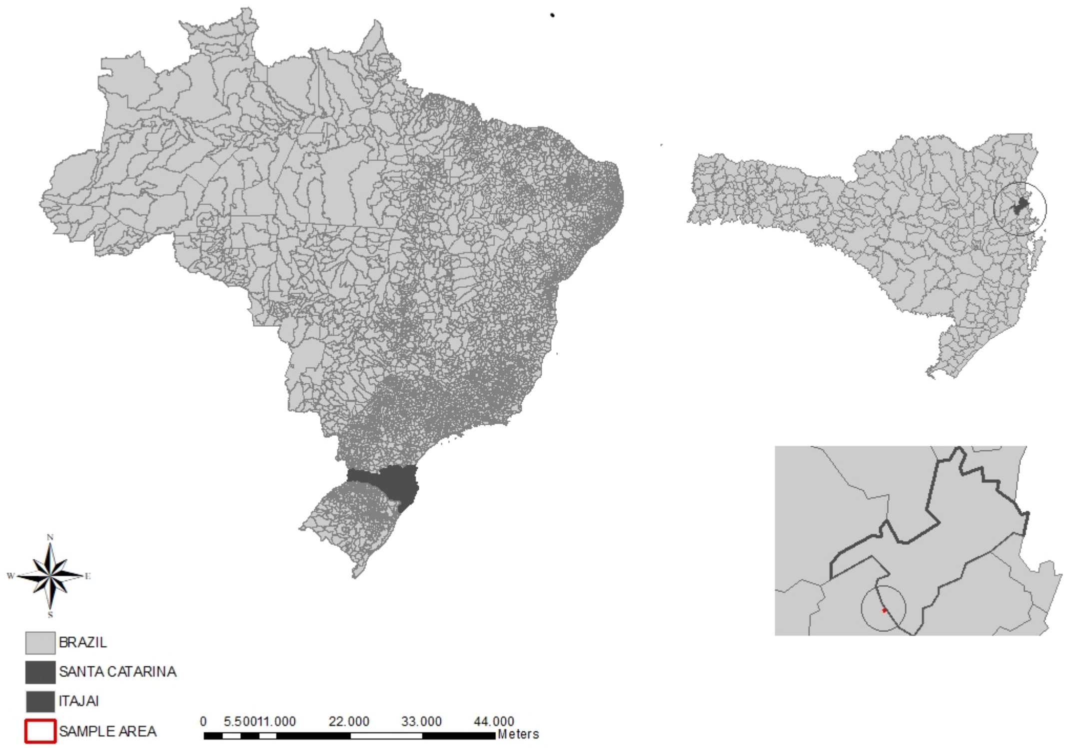
METHODS

Characterization of the study area

The study was conducted in an area of approximately 289,255 ha in the locality of Mineral in Itajaí, Santa Catarina, Brazil (27° 03' 39.45'' S and 48° 50' 17.60'' W) (Figure 1).

The soil in the experimental area is of the red-yellow clayey Cambisol type (Embrapa, 2018). The region's climate is classified as humid subtropical according to the Köppen climate classification. The average annual temperature is approximately 20.5 °C, with an average minimum temperature of 16 °C and an average maximum temperature of 24.0 °C. The average annual rainfall is 1,726.6 mm (Alvares et al., 2013).

Figure 1. Geographic location of the from the sample area in Itajaí (SC), Brazil.



Eucalyptus grandis was planted in February 2010, with a spacing of 2.0 m × 2.0 m and a density of 2,500 trees per hectare. This area has been used for eucalyptus reforestation since the 1980s.

Data collection

Sampling was carried out on a slope approximately 150 m long with a close to 50 m level difference between the base and the upper portion. The study area was divided into four altitudinal levels: top (145 m), 30 m (132 m), 20 m (122 m), and base (105 m). Four circular sampling units of 250 m² were allocated at each altitudinal level. The diameter at breast height (DBH) of all trees in the sampling unit was measured with a diametric tape. The height was determined using a Suunto clinometer. Based on these parameters, basal area and volume were determined.

Four soil samples spaced 15 m apart were randomly collected at 0–20 cm depth at each of these attitudinal levels. The samples were labeled, air-dried, crushed, sieved through a 2 mm mesh sieve, and sent to the EPAGRI Soil Analysis Laboratory. The following parameters were determined: clay content, pH, phosphorus (P), potassium (K), organic matter (MO), aluminum (Al), calcium (Ca), magnesium (Mg), sodium (Na), potential acidity (H+Al), cation exchange capacity (CEC), and base saturation (V).

Data analysis

The Shapiro–Wilk test was used to verify the normality of the data. The parameters that met the criteria were used for the analysis of variance, and the mean values were compared using the Tukey test at 5% probability. The values that did not meet the normality requirements were transformed using the Box–Cox method.

Regression analysis using dendrometric parameters as dependent and soil parameters as independent variables was performed to verify the relationship between dendrometric and soil parameters. Only variables that showed significant differences between the strata along the slope were used for these analyses. All calculations were performed using the statistical software Past and Microsoft Excel.

RESULTS AND DISCUSSION

Soil attributes

Statistical analysis indicated that the cation exchange capacity (CEC), pH, potential acidity (H+Al), potassium (K), and sodium (Na) were influenced by the position in the relief (Table 1). In previous studies, Artur et al. (2014) and Santos et al. (2016) confirmed the influence of microrelief on the spatial variability of soil chemical attributes. According to Klug et al. (2020), the effect of eucalyptus on the dynamics of nutrients in the soil may be related to differences in climate, soil, planted species, and the management of reforested areas, among others.

The highest mean CEC level was found at the top of the slope (44.88 $cmol_c$ dm^3). For all altitudinal strata, the values of this variable were high, according to the Soil Chemistry and Fertility Commission (2004). High CEC values generally occur where the organic matter and clay contents are high. These attributes contribute to an increase in negative loads favoring nutrient retention (Artur et al., 2014).

Regarding pH, the lowest value was found at 30 m (3.75) and the highest at the base (4.17). These values indicate soil with very high acidity (Soil Chemistry and Fertility Commission, 2004). The fact that the lowest pH values were at 30 m and at the top is probably due to the conformation of the relief that promotes the convergent movement of water, favoring the migration, dissolution, and percolation of mineral and organic constituents (Campos et al., 2007). Similar results to the present study were found by Zaia and Gama-Rodrigues (2004), who studied stands of *E. grandis*, *E. camaldulensis*, and *E. pellita* in Rio de Janeiro, Brazil; Cunha Neto et al. (2018), who evaluated *E. grandis* × *E. urophylla* plantations in Além Paraíba in Minas Gerais, Brazil, and Klug et al. (2020) who studied eucalyptus stands in the Campos de Cima da Serra Region, Rio Grande do Sul, Brazil.

Table 1. Soil parameters in different altitudinal strata of a slope in the municipality of Itajaí, SC, Brazil.

Parameters	Altitudinal strata			
	Top	30 m	20m	Base
Clay	34.25a	35.75a	37.50a	34.75a
MO (%)	4.82a	4.55a	3.32a	3.15a
V (%)	2.01a	1.63a	2.69a	2.90a
CEC ($cmol_c$ dm^3)	45.88a	38.57ab	34.31ab	37.94b
pH em água	3.85bc	3.75c	4.02ab	4.17a
H+AL ($cmol_c$ dm^3)	44.97a	37.96ab	37.96ab	27.17b
Al ($cmol_c$ dm^3)	10.12a	8.17b	5.47c	4.20d
P (mg kg^{-1})	4.02a	1.32a	1.65a	1.72a
K (mg kg^{-1})	30.50b	26.00b	29.75b	41.25a
Ca (mg kg-1)	0.42a	0.28a	0.40a	0.28a
Mg (mg kg^{-1})	0.35a	0.23a	0.40a	0.33a
Na (mg kg^{-1})	12.00ab	9.75b	11.0b	14.75a

MO: organic matter; V: base saturation; CEC: cation exchange capacity; H+Al: potential acidity; Al: aluminum; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; and Na: sodium.

The highest averages of H+Al and Al contents were found at the top (44.97 $cmol_c$ dm^3 and 10.12 $cmol_c$ dm^3) and the lowest at the bottom of the slope (27.17 $cmol_c$ dm^3 and 4.20 $cmol_c$ dm^3). Soil chemical composition, in terms of exchangeable aluminum and nutrient content, is an important indicator of soil quality (Klug et al., 2020).

The highest K value was found at the base of the slope (41.25 mg kg^{-1}). According to the Soil Chemistry and Fertility Commission (2004), these values are classified as low concerning soil fertility. Sodium values ranged from 9.75 mg kg^{-1} (at 30 m) to 14.75 mg kg^{-1} (at the base). The variability of soil chemical attributes is influenced by the complex interactions between soil formation factors and processes (Arthur et al., 2014).

Similar clay content values were observed between altitudinal strata, with no statistically significant differences. The highest value was found at 20 m (37.50%), and the lowest was at the top of the slope (34.25%). This result indicated that the top is a loss zone, with the dispersed clays possibly accumulating in the lower parts of the landscape.

Based on Campos et al. (2007), understanding the behavior of soil granulometry is important for understanding the distribution of sediments, the dynamics of slope formation, and for making inferences about the behavior of the soil. Therefore, granulometry is one of the most important attributes of soil because it is associated with the fragility of the soil. For instance, after considering the relief and climate conditions, the fragility of the soil increases as the clay content decreases because this scenario increases the susceptibility of the soil to erosive processes (Curcio, 2006).

Organic matter (OM) showed no statistically significant difference between s, ranging from 3.15% (base) to 4.82% (top). According to the Soil Chemistry and Fertility Commission (2004), these are classified as average. Organic matter is a fundamental component in maintaining soil quality and involves several physical, chemical, and biological processes. Imbalances in its supply and changes in decomposition rates can cause a reduction in the soil under planting, triggering degradation processes (Roscoe and Machado, 2002).

There was also no statistical difference in base saturation (V) between treatments, which ranged from 1.63% (30 m) to 2.90% (base). According to the Soil Chemistry and Fertility Commission (2004), the values fall into the very low class. It should be noted that the soil in the present study was dystrophic; that is, it had V values lower than 50%. Cunha Neto et al. (2018), who evaluated soil quality under *E. grandis* × *E. urophylla* forest stands, also found very low V values.

The P content was found at the top (4.02 mg kg^{-1}), with no statistical differences between treatments. According to the Soil Chemistry and Fertility Commission (2004), these values were very low. Corrêa Neto et al. (2007) evaluated the influence of edaphic and environmental attributes in *E. urophylla* stands and also observed higher P levels at higher altitudes.

The Ca and Mg values did not show statistically significant differences between treatments. According to the Soil Chemistry and Fertility Commission (2004), the contents of these elements were low. Santos et al. (2016), understanding the spatial variability of soil attributes is important to improve soil management and conservation practices.

Dendrometric characterization

The statistical analysis indicated that only the density of individuals and the diameter at breast height (DBH) showed significant differences between the altitudinal strata (Table 2). That is, only these variables were influenced by position in the relief. According to Tosta (2020), soil, climate, and relief directly affect the productivity of *Eucalyptus* stands.

The highest density was observed at the base of the slope (2,250 individuals), where individuals with smaller diameters were found. This can be explained by the fact that soils with better characteristics generally occur at the base of slopes, which leads to greater survival and initial growth of plants. However, the smallest average diameter in this altitudinal stratum may be linked to competition until this period. Different results were obtained by Corrêa Neto et al. (2007), who evaluated the influence of soil and environmental attributes on the dendrometric parameters of *E. urophylla*. They found that the stand in the upper third had the highest tree density.

Table 2. Dendrometric parameters of *Eucalyptus grandis* at 30 months of age in different altitudinal strata in the municipality of Itajaí, SC, Brazil.

Parameters	Top	30 m	20 m	Base
Density (ind ha^{-1})	1500ac	1575ac	1700ac	2250b
DBH (cm)	11.07ac	11.36ab	9.50cd	8.19d
Height (m)	10.68a	10.95a	10.63a	11.23a

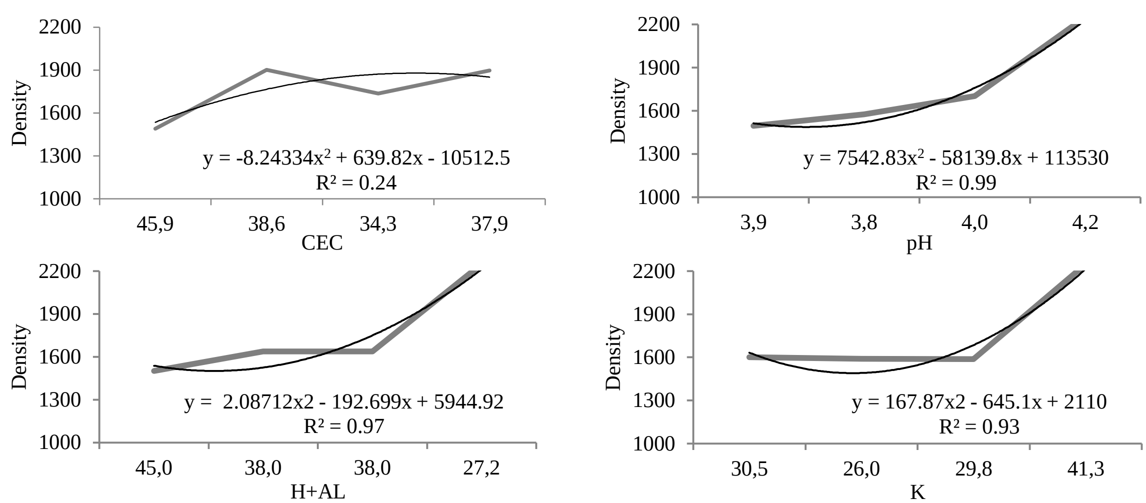
Basal area (m^2 ha^{-1})	16.10a	17.01a	13.63a	12.92a
Volume (m^3 ha^{-1})	89.04a	94.49a	76.63a	73.91a

DBH: diameter at breast height.

The highest DBH value was found at 30 m (11.36 cm). Corrêa Neto et al. (2007) also reported higher DBH values in the upper third. The height ranged from 10.63 cm (20 m) to 11.23 cm (base), and the volume from 73.91 m^3 ha^{-1}(base) to 94.49 m^3 ha^{-1}(30 m). According to Chagas et al. (2013), the terrain topography controls many hydrological, geomorphological, and pedological processes, influencing solar radiation, rainfall, surface runoff, evaporation, soil moisture regime, and, consequently, plant growth.

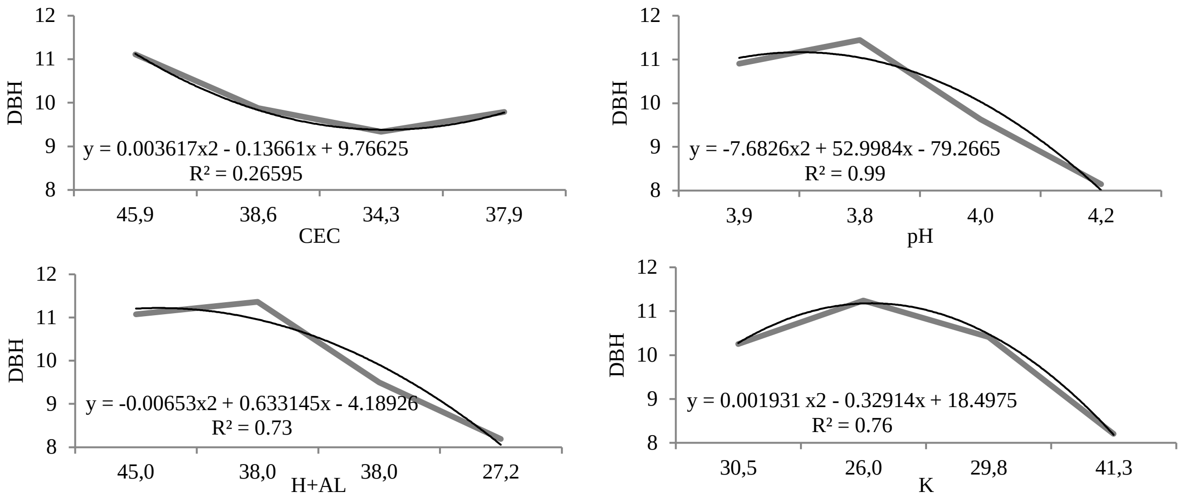
The relationship between dendrometric and soil parameters showed a high correlation with most of the variables analyzed (Figures 2 and 3). Tree density showed a positive relationship with pH, H+Al, and K, suggesting that higher values for these variables contributed to the survival and development of *E. grandis* for up to 30 months (Figure 2). In contrast, DBH values negatively correlated with the same soil parameters (Figure 3). In this aspect, it should be considered that the effect on DBH averages may be due to the density of trees and their respective levels of competition, a fact that should be further investigated. The results also showed that the effects of soil parameters were more pronounced at 20 m and at the base of the slope, where greater changes in these parameters occurred.

Figure 2. Regression analysis between density and soil parameters of a *Eucalyptus grandis* stand on a slope in Itajaí, SC, Brazil.



CEC: cation exchange capacity; H+Al: potential acidity; K: potassium; X-axis values, from left to right, follow the direction from top to bottom of the slope.

Figure 3. Regression analysis between DBH and soil parameters of a *Eucalyptus grandis* stand on a slope in Itajaí, SC, Brazil.



CEC: cation exchange capacity; H+Al: potential acidity; K: potassium; X-axis values, from left to right, follow the direction from top to bottom of the slope.

CONCLUSIONS

The soils of the present study are acidic and dystrophic.

Small variations in relief form conditioned variability in soil attributes and the growth of *Eucalyptus grandis* at 30 months of age.

The soil attributes CEC, pH, H+Al, and K showed a positive relationship with the density of *E. grandis* individuals at 30 months.

The edaphic variables had a greater effect on the density and DBH of the *E. grandis* stand at the base of the slope and 20 m.

AUTHORS' CONTRIBUTION STATEMENT

Conceptualization: LAS; Data curation: LAS; Formal analysis: LAS; Funding acquisition: LAS, TABF; Investigation: LAS, TABF, ; Methodology: LAS; Project administration: LAS; Resources: LAS, TABF; Supervision: LAS, KFS; Validation: LAS; Visualization: LAS, KFS; Writing – original draft: LR, SC, HKC, RRS, NNP; Writing – review & editing: KFS, LAS.

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

RESEARCH DATA AVAILABILITY STATEMENT

The entire dataset supporting the results of this study was published in the article itself.

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